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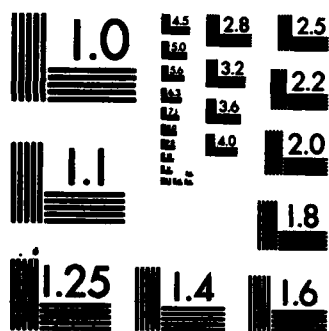
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Eye movements determine the location and velocity of the retinal image. Thus, to understand how we see it is necessary to understand both how eye movements are controlled and how they affect visual information processing. The proposed research is concerned with both problems. Specifically: (1) The effect of expectations on smooth eye movements; The eye moves smoothly in the direction of expected future target motion. Experiments will determine (1) how expectations and guesses about the direction of future motion are formulated and (2) the relative contributions of expectations and retinal image motion to

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smooth eye movements. (U) The effect of saccades and saccade-like stimulus perturbations on visual information processing: Saccades continually displace the retinal image, yet we see the world as a single coherent picture. Experiments will find out whether the visual system selectively tolerates rapid lateral displacements, or whether the decision to move the eye is required. (U) Programming sequences of saccades: Experiments will show whether sequences of saccades can be pre-programmed, and whether use of such sequences improves performance of visual tasks.

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EYE MOVEMENTS AND VISUAL INFORMATION
PROCESSING

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ABSTRACT

Eye movements determine the location and velocity of the retinal image. Thus, to understand how we see it is necessary to understand both how eye movements are controlled and how they affect visual information processing. The proposed research is concerned with both problems. Specifically:

(1) <u>The effect of expectations on smooth eye movements.</u> The eye moves smoothly in the direction of expected future target motion. Experiments will determine: (1) how expectations and guesses about the direction of future motion are formulated and (2) the relative contributions of expectations and retinal image motion to smooth eye movements.

(2) <u>The effect of saccades and saccade-like stimulus perturbations on visual information processing.</u> Saccades continually displace the retinal image, yet we see the world as a single coherent picture. Experiments will find out whether the visual system selectively tolerates rapid lateral displacements, or whether the decision to move the eye is required.

(3) <u>Programming sequences of saccades.</u> Experiments will show whether sequences of saccades can be pre-programmed, and whether use of such sequences improves performance of visual tasks.

Progress Report   (January 1, 1983 to December 31, 1983)

1. Publications

Kowler, E. and Sperling, G. Abrupt onsets do not aid visual search.
   Perception and Psychophysics, 34, 307-313.

Kowler, E., Martins, A. and Pavel, M. The effect of expectations on slow
   oculomotor control: Anticipatory smooth eye movements depend on prior
   target motions. Vision Research, in press.

2. Presentations

Kowler, E. and Sperling, G. The role of saccade-like stimulus transients in
   visual information processing. Association for Research in Vision and
   Ophthalmology, May, 1983.

Martins, A. Kowler, E. and Palmer, C. Contribution of the slow control and
   smooth pursuit oculomotor subsystems to the tracking of sinusoidal motions.
   Presented at the annual meeting of the Optical Society of America,
   October, 1983.

Kowler, E., Anton, S. and Lopez, L. Reading desrever text. Presented at the
   annual meeting of the Psychonomic Society, November, 1983.

3. Research in progress.

   Smooth pursuit of small amplitude sinusoidal motions. Subjects used
smooth eye movements to track small amplitude (3.75' to 60' p-p) sinusoidal
motions of frequencies 0.65 to 5.0 Hz. Smooth pursuit was evident
(i.e., mean eye speed during smooth pursuit was greater than mean eye speed
during slow control) at all stimulus frequencies and at all stimulus
amplitudes except the smallest. Smooth pursuit gain (mean eye speed/mean
stimulus speed) decreased as target frequency increased and as target amplitude
increased (see Figure 1).
   Two surprising characteristics of smooth pursuit were observed:
   (1) The dependence of smooth pursuit gain on target amplitude

could be eliminated by subtracting a constant, which varied as a function
of target frequency, from mean eye speed before computing gain.
Specifically, letting G'(f,a) denote this re-computed gain:

$$G'(f,a) = \frac{E(f,a) - K(f)}{T(f,a)}$$

where E(f,a) is mean eye speed for a given frequency (f) and amplitude (a),
T(f,a) is mean stimulus speed for a given frequency and amplitude and
K(f) was the constant which, for each frequency,
minimized the differences in G'(f,a) for the four stimulus amplitudes (60', 30',
15', and 7.5') at which smooth pursuit was observed.   Figure 2 shows
G'(f,a) as a function of stimulus frequency.

Our results suggest that smooth eye movements are determined by
two separate and independent processes, one which contributes a constant eye
speed and the other which responds linearly to stimulus speed. Our results
also suggest that the process contributing the constant may be the slow
control subsystem. This suggestion is based on the fact that the average
value of K(f) was about the same as the average speed of slow control
(i.e., smooth eye speed when the stimulus was stationary).
The average value of K(f) for subject RS was 13.8 (S.D=6.1, N=9) and
his average slow control speed was 17.0 minarc/sec (S.D.=13.8, N=2742).
The average value of K(f) for subject EK was 22.4 (S.D.=8.3, N=9) and
her average slow control speed was 23.2 minarc/sec (S.D.=18.7, N=2392).
Thus, slow control and smooth pursuit may be separate oculomotor subsystems,
a possibility which has been considered ever since Nachmias (1961) suggested
that slow control was actually smooth pursuit of a zero velocity target.

(2) Pronounced systematic drifts were superimposed on the oscillations

of the eye. These drifts occurred at all but the highest frequencies and smallest amplitudes. Drift direction was idiosyncratic and was not consistent with the subject's systematic drift direction in the dark. Thus, inactivation of the slow control subsystem did not produce the systematic drifts. The drifts created large position errors (up to 2 deg) but position errors did not abolish the oscillations. These results show that smooth eye movements do not correct position errors. Instead, they create position errors while continuing to reduce retinal slip. (See Figure 3).

These results will be presented at the October meeting of the Optical Society.

Reading reversed text. Subjects read text which was transformed in a variety of ways in an attempt to determine the relative contributions of oculomotor habits and visual recognition to visual information processing. Reading is a useful task to study because both oculomotor habits and the visual recognition of words and letters are well-learned. Previous research has suggested that oculomotor habits play an important role in reading based on findings that reading text from left to right is faster than reading text from right to left (Koler, 1968).

We used text in which letters were either oriented normally or were rotated about the x, y or z axis. In addition, the order of letters and words were either normal or changed in one of the following ways: (1) the order of letters in a line were reversed (e.g., "Hello there" becomes "ereht olleH"), thus requiring subjects to read from right to left; (2) the order of words in a line was reversed while the order of letters in a word was unchanged ("there Hello"), again requiring subjects to read from right to left; and (3) the order of letters in a word was reversed

while the order of words in a line was unchanged ("olleH ereht"), requiring subjects to read from left to right.

He used short passages (less than 98 characters) taken from Science which were read under the instruction to comprehend accurately the entire passage. A multiple choice question was asked after each passage and the subjects' scores (98% correct) confirmed that they followed the instructions. The dependent variable was reading time.

Reading time was not affected by the direction of scan of a line (left to right or right to left). Reading time was also not affected by word order in that reading time was the same whether the order of letters in a word was the same as or opposite to the order of words in a line (see Table 1). Reading time was affected by the appearance of letters in a word produced by changing the orientation of letters or by changing the order of letters in a word. These results suggest that reading time is limited by visual processes involving the rapid recognition of letters and words and not by oculomotor habits. Similar experiments, to determine the role of visual and oculomotor habits in other tasks, such as search, are being planned. An abstract describing the present results was submitted to the Psychonomic meeting.

Effect of stationary and moving backgrounds on smooth eye movements. Murphy et al. (1975) found that subjects can maintain the line of sight on a stationary point in the presence of a moving background (a high contrast squarewave grating moving within a 4 deg diameter region). This result demonstrated the capacity to select the input stimulus for slow control. The following experiment, performed in H. Collewijn's laboratory, extends Murphy et al.'s findings by showing that the ability

to select the input stimulus for smooth eye movements applies: (1) to the smooth
pursuit of moving targets, (2) when
the selected target and the background are superimposed within a large visual
field, and (3) when the selected target is faint and the background vivid.

The stimulus consisted of two overlapping fields (76 deg by 87 deg)
of random dots (small rectangles, 7.1 by 9.5' with 1.0 dots/square degree).
One field of dots remained
stationary and the other moved to the left at 1.17 deg/sec. Subjects were
instructed to either maintain the line of sight on the stationary field
or to use smooth eye movements to pursue the moving field. Their performance
was perfect. Eye velocity when the line of sight was maintained on the
stationary field was unaffected by the presence of the moving field. Similarly,
eye velocity when the moving field was tracked was unaffected by
the presence of the stationary field. The same results were obtained
when the density of the random dots was increased (8.8 dots/square degree)
and when the intensity of either of the fields was reduced by
a factor of 5. These results are summarized in Table 2.

These results demonstrate that the capacity to select the input to smooth
eye movements applies even under difficult conditions, namely, when
attention to a selected region of space is not sufficient to guarantee
the input, and when the selected field was faint relative to the other field.
This capacity is useful because it ensures that selected targets can be
maintained on the fovea regardless of the presence of other targets in
the field. These results also raise a new question because sometimes
influence of stationary backgrounds on smooth pursuit of
moving targets does occur (Collewijn, personal communication), i.e., sometimes
subjects do not perform at capacity levels. It is possible that failure to

perform at capacity levels occurs because subjects do not apply sufficient attention to the selected target. Future experiments are being planned to examine this possibility by asking subjects to fixate stationary or moving targets while simultaneously making psychophysical judgments about other targets in the field. A manuscript describing the present results is in preparation.

Figure Legends.

Figure 1. Smooth pursuit gain (mean 50-msec eye speed/mean 50-msec target speed) as a function of stimulus frequency for subjects RS (left) and EK (right)

Figure 2. Adjusted smooth pursuit gain (mean 50-msec eye speed - K / mean 50-msec target speed) as a function of stimulus frequency for subjects RS (left) and EK (right). K=the constant that minimized the differences among gains at each stimulus frequency.

Figure 3. Mean 50-msec eye velocity as a function of stimulus frequency for subjects RS (left) and EK (right).
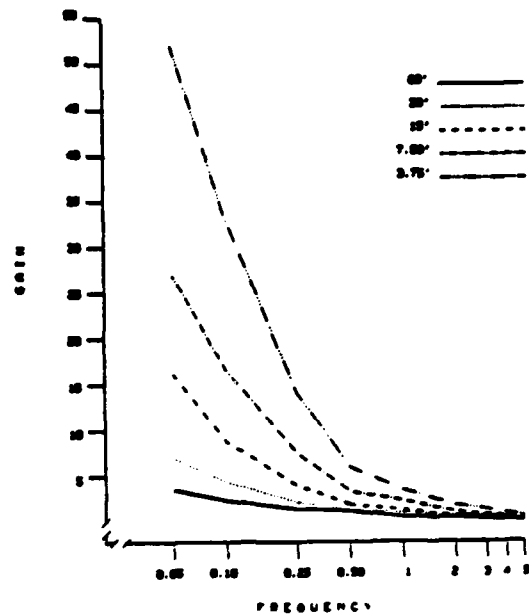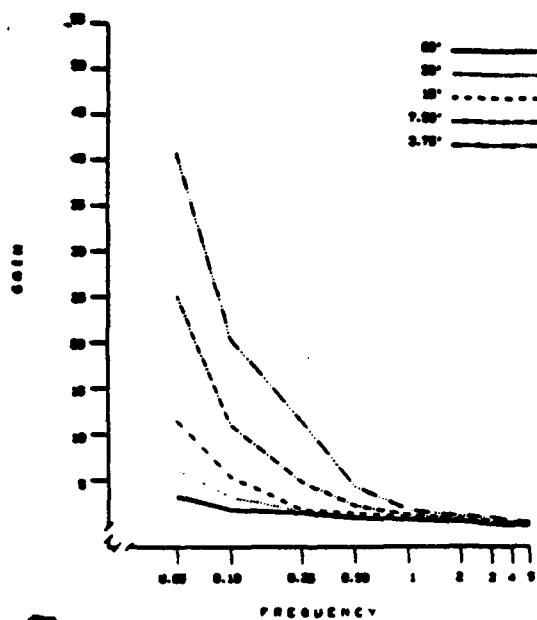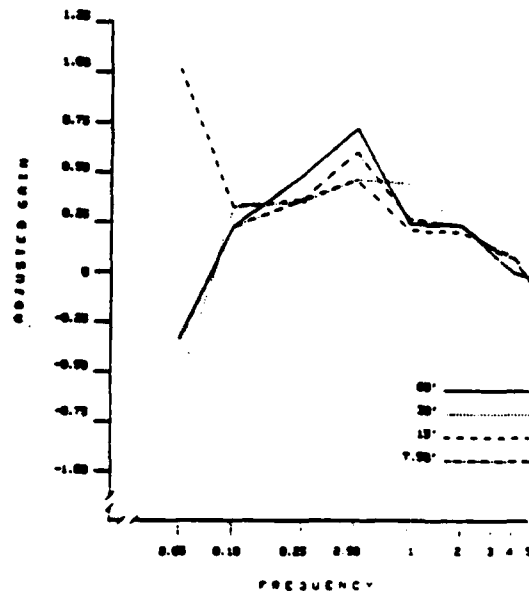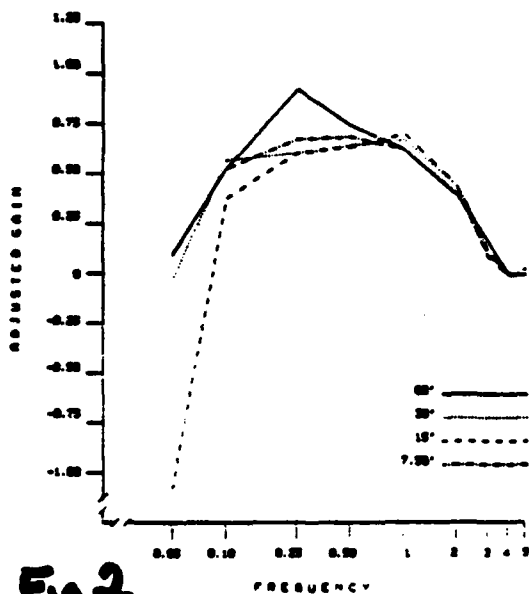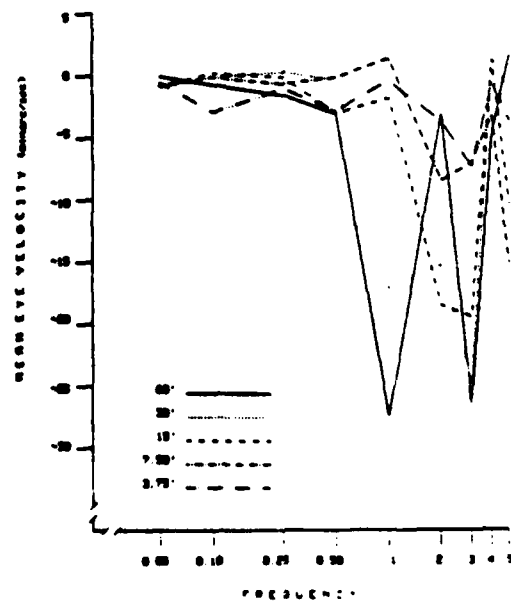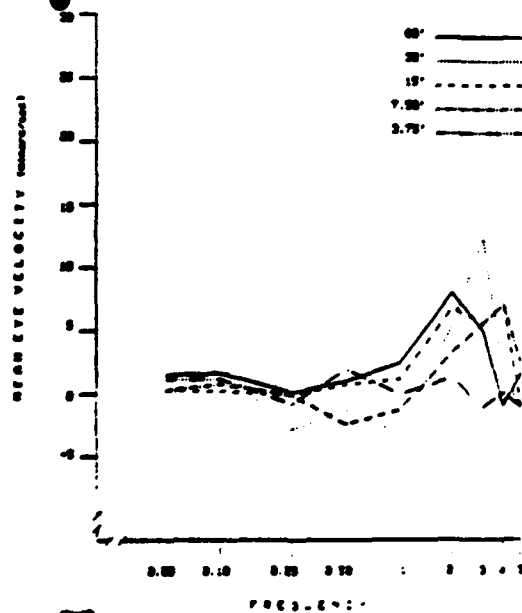
Fig. 1

Fig 2

Fig 3

Table 1. Mean reading times (sec/letter) for passages read from
left to right (L—>R) and right to left (R—>L) and for passages in
which the order of letters in a word was the SAME as and OPPOSITE to the
order of words in a line.

	Subject LL			Subject EK	
	Mean	N		Mean	N
L—>R	0.35 (0.17)	40		0.42 (0.25)	40
R—>L	0.32 (0.12)	40		0.42 (0.28)	40
SAME	0.32 (0.13)	40		0.42 (0.27)	40
OPPOSITE	0.35 (0.16)	40		0.42 (0.26)	40

Standard deviations are in parentheses. The number of passages (N) on which
each mean is based is also shown.

Table 2. Mean eye velocities (min arc/sec) in the presence of the STATionary
field only, the MOVING field only, and BOTH fields under the instruction
to maintain the line of sight on the stationary (STAY) or to TRACK the moving
field. Results are shown separately as function of field DENSITY (LOW or HIGH)
and luminance (BRIGHT or DIM).

Subject RS

	LOW DENSITY BOTH BRIGHT		HIGH DENSITY BOTH BRIGHT		HIGH DENSITY STAT DIM		HIGH DENSITY MOVING DIM	
	Mean	N	Mean	N	Mean	N	Mean	N
STAT:STAY	0.021	30	0.009	10	-0.004	10	0.013	10
BOTH:STAY	0.012	29	-0.032	10	0.056	10	0.013	10
MOVING:TRACK	1.216	28	1.280	10	1.272	10	1.291	10
BOTH:TRACK	1.241	29	1.239	10	1.269	10	1.197	10

Subject HC

	LOW DENSITY BOTH BRIGHT		HIGH DENSITY BOTH BRIGHT		HIGH DENSITY STAT DIM		HIGH DENSITY MOVING DIM	
STAT:STAY	-0.051	40	-0.064	20	-0.030	20	-0.045	20
BOTH:STAY	-0.024	40	-0.053	20	-0.070	20	-0.070	20
MOVING:TRACK	1.198	40	1.196	20	1.200	20	1.157	20
BOTH:TRACK	1.173	40	1.198	20	1.179	20	1.142	20

Negative means indicate rightward velocities. The number of trials (N) on which
each mean is based is also shown.

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